

Innovative Service and Performance Focused Hands-on End-to-End System Integration Approach in Teaching Undergraduate Data Communications and Telecommunications

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Abstract – Undergraduate courses for Data Communications and Telecommunications cover services from a network technology perspective more so than they cover network technologies from a service perspective. Thus, critical issues such as interoperability and end-to-end system integration in support of new service and application ideas are left unexplored until post graduation, on-the-job training. Up until now, such explorations have not been easy or practical to execute in an undergraduate laboratory and/or classroom environment. In this paper, we present an innovative approach based on the design and implementation of a hands-on experiment where the students defined a new converged data and voice service and prototyped such a service using emulated network links and nodes. In this experiment, a specific service selected by the students for implementation supports real time remote wireless monitoring of a patient location and vital signs data involving three different locations (control, ambulance dispatch and medical centers). The emulated components involved a GPS device, wireless networks configured for ad hoc and wireless distribution system (WDS) topologies, Fiber Optic Communication system, and wireless/wire line based IP Private Branch Exchange (PBX). The class was successful in demonstrating the features and performance of the prototyped service under different network quality-of-service (QoS) conditions. Also, provided in this paper are the key learning identified both by the students and the instructor/coach perspectives. We believe that the experiment was a success and plan to enhance and apply this approach in future classes.

Index Terms – Hands-on, System Integration, Converged Data and Voice, Real Time Application, Problem based learning (PBL), End-to-End Network Emulation.

INTRODUCTION

Undergraduate college students pursuing a major in data communications and telecommunications are usually provided opportunities to investigate and analyze the performance requirements of data communications and telecommunications

real time services and applications. These typically take the form of case studies, research projects, or research papers and are conducted either by the individual student or by 2- to 4-person teams. Providing students with hands-on, end-to-end networking experience can be difficult and expensive. However, in the cases where the students are given the opportunities to perform hands-on projects, they are typically focused on specific network transport or switching technologies such as Fiber Optics, Wireless, Cellular, Satellite, Switching, or Routing and on how they are used in support of data communications and telecommunications services. The primary focus is on the network technology, not the service; that is, it is on presenting services from a “technology focused” perspective, rather than network technology from a “service focused” perspective.

Moreover, when students typically work on projects whether individually or in teams, they perform their project with little, if any, consideration as to the role their project plays in the realization of the end-to-end data communications and telecommunications services or applications. In addition, they pay little attention as to how their project (subsystem) should be integrated and interfaced to other associated subsystems in support of the end-to-end service or application.

In data communications and telecommunications education, especially in the system approach area, it is usually not feasible, or at least not practical, to provide students with a “real” environment in which to conduct experiments. Therefore, network simulators such as OPNET [1] are frequently employed over real environment or network emulation. One of the critical differences between the simulation and emulation approaches is that the former does not render an opportunity for the students to be challenged with implementation, integration and interfacing issues, whereas the latter must consider the physical as well as the protocol interoperability and end-to-end quality-of-service (QoS) related issues. While both techniques can be utilized, emulated environments are clearly superior to simulated environments, for they allow experimentation from a wider variety of service integration and convergence perspectives. Even if the emulation is a small scale compared to the real environment, it still offers certain challenges that prepare the

student well for the real world, saving the potential employer significant training investment.

In the Integrated Science and Technology (ISAT) program at James Madison University, we strongly believe, as do many others [2-3] that students learn more effectively from courses that provide for active involvement in hands-on practical activities. We also believe that when they take ownership of their learning through problem solving projects, they better retain the knowledge and apply their learning both in other classes and in the work environment upon their graduation. Problem-based learning (PBL) has been recognized [4-5] as an effective approach to developing and honing the students' lifelong independent learning skills. Also, the National Research Council has recognized that creating engaging laboratory and classroom experiences is a challenge to effective undergraduate education in Science, Technology, Engineering, and Mathematics (STEM) disciplines [6-7].

In an attempt to tackle the issues mentioned above, we have designed, developed and implemented an experiment using an end-to-end, "service focused" and systems integration approach. The students were challenged to propose an end-to-end service and use currently available laboratory equipment to emulate and prototype a real-world environment. Students implemented this simplified end-to-end service as a course project. The implementations took advantage of a number of free, open-source software packages and surplus equipment.

In this paper, we document our efforts at creating an emulated data communications and telecommunication environment and describe the integration of a practical example of a service focused project. We also share the details of how the implementation of this experiment was performed by the students as part of an undergraduate data communications and telecommunications course with minimal available resources. Moreover, we describe the key learning both by the students and the instructor whose role was a coach rather than an instructor throughout the project life cycle.

We organized this paper as follows. The Project Criteria and Process section provides a list of criteria utilized in the execution of this project and a brief description of the process used in the management of the teams and their deliverables. The Service/Application Definition section gives a detailed description of the service as defined through the dialog between the instructor/coach and the students. In the Teams Organization and Responsibilities section, we provide the projects and roles of the network technology and integration teams. In the Results and Analysis section, we describe the teams' findings. Finally, key learning and future recommendations are presented in the Conclusion and Recommendations section.

PROJECT CRITERIA AND PROCESS

The project was created to comply with a common set of project selection criteria. They are:

- Build upon or enhance students' knowledge of one or more course learning objectives.

- Expose students to real-world service development experience wherever possible.
- Stay within the project budget of \$500. Use existing hardware and lab equipment. Use free or open-source software.
- Select technologies that can be emulated in lab environment.
- Use operating system platforms that students are familiar with (Windows and/or Linux).
- Involve intensive system integration.
- Require students to function in small and large teams.
- Require students to demonstrate report writing and presentation skills.

Using these criteria, the twelve (12) junior and senior students in the Data Communications and Telecommunications class were divided into five (5) teams (see Teams Organization and Responsibilities section). Each team selected a network transport or switching technology from a pool of possible building blocks that could be used to carry data and voice traffic.

The entire class met once a week with one instructor/coach and one lab assistant for 100 minutes over an entire semester. For the first 20 minutes, each of the network technology teams provided a brief project status with emphasis on the challenges and their proposed solutions. The integration team was allowed 10 minutes to describe their interactions with the network technology teams and the possible application scenarios/exercises of the end-to-end emulation environment.

SERVICE/APPLICATION DEFINITION

In a class discussion, a number of possible applications were discussed and briefly explored. Eventually, the class converged on the remote monitoring of a patient's location and vital signs (such as, temperature, heart beat and blood pressure) on a real-time basis with the capabilities of automatic medical emergency dispatching and two-way communications between a control monitoring center and the primary physician at a medical service center.

As part of the service definition, the class established and designated four (4) different locations as follows:

- Location 1 with PC1 representing a mobile user under monitoring,
- Location 2 with PC2 representing a remote monitoring and control center,
- Location 3 with PC3 representing a central dispatch center, and
- Location 4 with PC4 representing a central assessment and diagnostic center (e.g., medical service center).

These locations and the links between them are equipped with network transport and switching capabilities supporting data transfer and real-time voice applications. Figure 1 shows

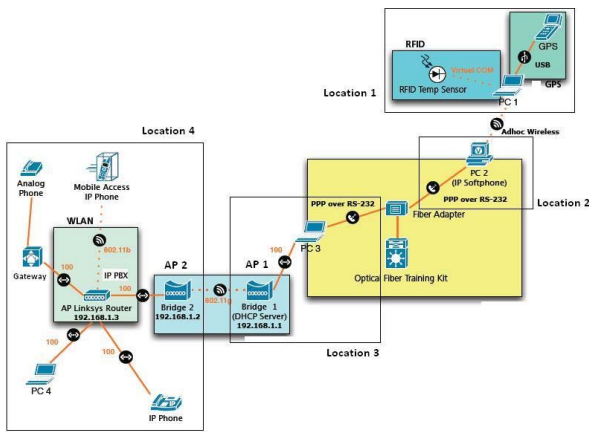


FIGURE 1
END TO END INTEGRATED COMMUNICATIONS SYSTEM

the end-to-end communication network with the four locations and the associated equipment deployed at these locations.

TEAMS ORGANIZATION AND RESPONSIBILITIES

Each team was responsible for a specific network technology, except for one team that was designated as the integration team. In Table I, we list the teams, their defined roles, their network technologies subsystem and at which locations their subsystem resides.

TABLE I
TEAMS, ROLES, NETWORK TECHNOLOGIES AND LOCATIONS

Team	Role*	Network Technologies Subsystem	Location
Team 1	C, A, Z	GPS and RFID	1
Team 2	C, A, Z	Optical Fiber Training Kit (OFT)	2 & 3
Team 3	C, A, Z	Wireless Distribution System (WDS)	3 & 4
Team 4	C, A, Z	IP Telephony	4
Team 5	I, A, Z	Adaptors & Common Services	

*C: Configuration, A: Analysis, Z: Performance Characterization, I: Integration

The role of each team was to configure the selected network technology so that it would be capable of carrying data and/or voice traffic. Each network technology team was also charged with the development of a stand-alone set of experiments, with a complete configuration, demonstrating the capabilities and performance characteristics (e.g., bandwidth, speed, throughput and latency) of their respective network technologies. In addition, they were to provide the integration team with a detailed account of the available input and output interfaces of their respective network technology subsystem.

The integration team’s main objective was to establish end-to-end data and voice channels that meet the quality of service requirements of the data and voice real time applications mentioned above. Towards achieving this objective, the team members were to gather detailed specifications about the input and output interfaces of each network technology and were expected to identify problems and propose solutions related to

- performance bottlenecks in the end-to-end connection,
- interoperability and interface interconnection issues, and
- common services components and adaptors.

This required that the integration team negotiate possible modifications or changes to the network technology processing and interfaces with the network technology teams.

I. NETWORK TECHNOLOGY TEAMS

Team 1 focused on the collection of location and one environment or vital signs parameter data, for example, temperature. They identified DELMORME, Earthmate ® GPS LT-20 [8] to meet the criteria for cost effectiveness as well as three (3) feet location accuracy. Earthmate LT-20 is equipped with a USB physical interface and is delivered with DeLorme Serial Emulator. This team attempted to construct an RFID (Radio Frequency Identification) system based on [9] that was developed specifically for real-time temperature monitoring, but faced a number of technical challenges and problems. In the face of the stringent time constraint, they decided to create a VB.NET-based program to simulate what a working RFID would have done: passing temperature readings to a PC via a serial port. The program defaults to 72 °F and changes up and down by 1 °F degree every five (5) seconds, to simulate fluctuation in the monitored temperature. The program allows the output data to be stored in a file, in addition to passing the data to a serial port (virtual or real) in real time. Also, it allows the user to configure the serial port settings. Figure 2 shows the user interface for the temperature simulator running on a PC under the Microsoft Windows XP operating system.

Team 2 explored the Benchmark Optical Fiber Training Kit (OFT) [10] and determined that the received signal level peaks at 2 MHz for the fiber optics channel, confirming that the OFT could be used to emulate a backbone fiber network for the purpose of this project. However, interfacing to the OFT kit to establish data and voice communications channels was a challenge. The OFT is equipped with transmit and receive expansion ports (40-pin Flexible Ribbon Connector (FRC)) for external interfacing, which requires a special adaptor. The solution to this issue (to be discussed later)

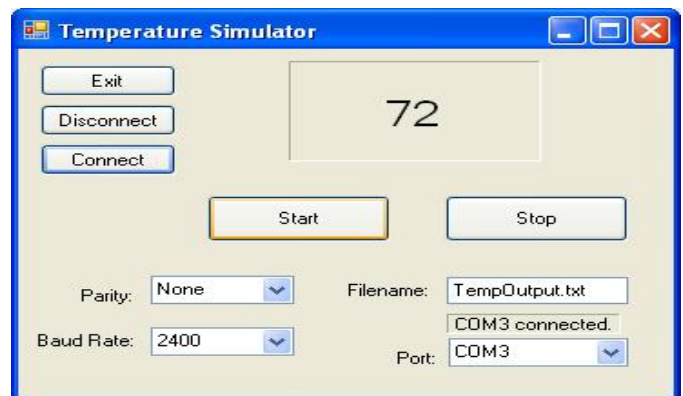


FIGURE 2
FRONT END OF ROOM TEMPERATURE SIMULATOR
RUNNING ON WINDOWS XP

required negotiation with the integration team.

Team 3 focused on investigating how to set up data and voice communication channels over a wireless network. They proposed the use of 802.11 wireless Access Point (s) (APs) in a configuration known as Wireless Distribution Systems (WDS) [11] to emulate a WAN based wireless backbone. They upgraded two Buffalo WHR-G54S IEEE 802.11b/g Wireless Broadband Router and Access Point with DD-WRT ver23 [12]. DD-WRT is a free Linux-based firmware and is licensed under the GNU General Public License version 2. The main reason for the firmware upgrade was to have access to the WDS feature and the ability to throttle the available bandwidth/capacity between the two routers/APs.

Team 4 was responsible for setting up an IP PBX (Private Branch Exchange) and enabling VoIP connectivity between different types of voice stations. Initially, the team selected the implementation of Asterisk™ [13] on a desktop. However, they identified a far less expensive and highly maintainable solution. The solution is based on the use of a Linksys WRT54GS residential wireless gateway with an upgraded firmware OpenWRT Whiterussian rc6 [14]. The upgrade transformed WRT54GS into a Linux platform running two applications: 802.11 wireless Router/Access Point and IP PBX Asterisk. The Asterisk IP PBX application could be accessed through wireless and wire-line connections in locations 4 and through X-lite Soft Phones in locations 2 and 3. The team set up six (6) extensions for six (6) different SIP based devices available in these locations.

II. SYSTEM INTEGRATION TEAM

The integration team started its effort by gathering interface specifications for the various subsystems making up the end-to-end network. Table II shows the data gathered. To

TABLE II

LOCATION, INTERFACES (PHYSICAL & PORT/SOCKET)

Location	Interface	Physical	Port/Socket
1	GPS LT-20 to PC1	USB	Virtual COM
1	Temperature Simulator on PC1	Internal	Virtual COM
1	TCP-COM on PC1	Internal	COM to TCP/IP
1-2	PC1 to PC2	802.11g	TCP/IP - COM
2	TCP-COM on PC2	Internal	Virtual COM
2	COM-Street Atlas on PC2	Internal	Virtual COM
2	X-Lite on PC2 on DCC	Internal	IP on PPP
2-3	PC2 to Adaptor	RS-232	N/A
2-3	Adaptor to 40 pin FRC OFT	40 pin FRC	TDM
2-3	TDM/Fiber to Fiber/TDM	850 nm	256 kb/s
2-3	40 pin FRC OFT to Adaptor	40 pin RFC	TDM
2-3	Adaptor to PC3	RS-232	N/A
3	X-Lite on PC3 on Ethernet	Internal	IP on 802.3
3	PC3 to AP#1	Ethernet	IP on 802.3
3-4	AP#1 to AP#2	802.11g	IP on 802.11
4	AP#2 to Linksys/Asterisk	Ethernet	IP on 802.3
4	X-Lite on PC4	Internal	IP on 802.11
4	PC4 to Linksys/OpenWRT	802.11g	IP on 802.11
4	ZyXEL to Linksys/OpenWRT	802.11b	IP on 802.11
4	Linksys VoIP GW to Asterisk	Ethernet	IP on 802.3
4	Analog Phone to Linksys GW	RJ-11	Tip/Ring

emulate a mobile user whose location and health/environment conditions data are monitored and transferred on a real-time basis from Location 1 to Locations 2 and 3, an Ad Hoc wireless connectivity between PC1 and PC2 was established. Next, they were faced with the challenge of mapping serial ports (real or virtual) to TCP/IP sockets to transfer the monitored data from Locations 1 to locations 2, 3 and 4. Initially, they thought of developing their own application for the conversion but later voted against it. They opted to go with commercially available software known as TCP-COM [15]. By configuring an instance of TCP-COM on each of PC1 and PC2, they were successful in establishing a remote access of the PC1 collected data via a COM port created by the TCP-COM instance on PC2. On configuring Street Atlas USA 2007 PLUS software (module of the Earthmate GPS LT-20 package) installed on PC2 to receive NMEA (National Marine Electronics Association) 0183 protocol compliant location data on, the mobile user coordinates, speed and elevation were presented on a city or county map on PC2. For the temperature data to be also transferred to Location 2, the integration team negotiated with a senior student to develop a COM Multiplexer/De-multiplexer program, which combines/splits data from/into two COM serial ports.

To transfer data and voice traffic using the OFT kit, the integration team had two options: either to purchase two Benchmark RS-232 Interface Modules or build their own interfacing circuitry. The integration team negotiated with the lab assistant to build a simple expansion port to RS-232 adaptor for interfacing PC2 and PC3 to the OFT kit via RS-232 as shown in Figure 3. Although the integration team was able to transfer data between PC2 and PC3 over RS-232 and OFT, they were initially unsuccessful in establishing a VoIP channel between PC2, PC3 and/or PC4 using the serial connection. This challenge was resolved by setting up a Direct Cable Connection (DCC) [16] between PC2 and PC3. This basically establishes a WAN Point to Point (PPP) [17] IP channel over direct serial ports and thus enabling TCP/carried traffic, such as, (SIP) and Real Time Protocol (RTP) for VoIP.

Next, the integration team turned their attention to setting up connectivity between Locations 3 and 4. First, they

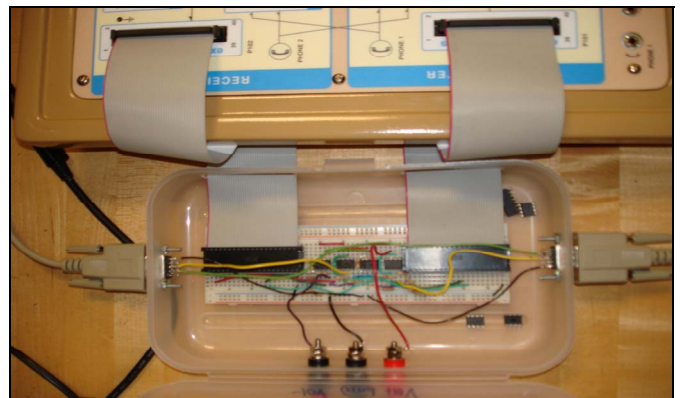


FIGURE 3
RS-232 TO OFT EXPANSION PORT ADAPTOR

connected PC3 at Location 3 to one of the LAN ports on Buffalo Wi-Fi Router/AP#1 and connected the Asterisk router in Location 4 to one of the LAN ports on Buffalo Wi-Fi Router/AP#2. The integration team negotiated with team 3 and designated AP#1 as the Dynamic Host Configuration Protocol (DHCP) server for the entire network. They enabled the DHCP server function on AP#1 and disabled the same on AP#2 and the Linksys AP running Asterisk IP PBX.

RESULTS AND ANALYSIS

The integration team developed four (4) experiments demonstrating the end-to-end performance for data transfer and voice application. In the first exercise, they demonstrated data transfer of location data (GPS) and temperature monitored (RFID simulator) from Location 1 to 2 all the way through Location 4. The data transmission between the PCs was very smooth and seemed almost instantaneous.

The next three (3) exercises focused on VoIP channel set up and voice communication. First, the integration team requested that Team 3 configure the WDS connection with limited bandwidth at about 15 kbps. Then they launched X-Lite Soft Phone on PC3 at Location 3 and set it up to register with Asterisk IP PBX at Location 4. They were successful in initiating a connection between Location 3 and one of the phone stations at Location 4 as was evident by the ringing of phone associated with the called extension. However, when the receiver was picked up at Location 4, voice communication was extremely choppy and delayed. This was when they discovered that the connection bandwidth between Locations 3 and 4 was not sufficient to meet the bandwidth requirements for VoIP communications. When the bandwidth of the WDS connection increased to 100 kbps, it was then possible to have an acceptable channel quality for an IP telephony communication.

The next exercise was to establish a voice connection between Location 2 and Locations 3 and 4. They launched X-Lite Soft Phone on PC2 at Location 2 and set it up to register with Asterisk IP PBX at Location 4. They initiated an IP Telephony call from the Analog Phone at Location 4 to the X-Lite Soft Phone on PC2. The team observed that the phone at Location 2 rang, but voice communications was not possible; this was even worse than the case where the bandwidth between AP#1 and 2 was limited to 15 kbps. They concluded that the bandwidth of the connection between PC2 and PC3 was adequate for SIP transactions (to set up a connection) but not adequate for the codec selected for RTP packets, that is, VoIP packets. They removed the OFT and the adaptor from the end-to-end connection and replaced with a null modem cable. This enabled them to set up the PPP connection at 115.2 kbps. This bandwidth was then sufficient and enabled them to make voice IP calls between Locations 2, 3 and 4. They scheduled the work on the adaptor to the OFT to future projects.

In the case of Voice over IP, they determined using Bandwidth Calculator for VoIP [18] that for GSM codec (13.3 kbps), the bandwidth requirement is 31.6 kbps for

RTP/UDP/IP carrier over PPP frame. This confirmed why the connection between AP#1 and AP#2 at 15 kbps channel on the Adaptor/OFT were not adequate to support VoIP traffic. As to the SIP set time, it was measured to be about 8 seconds at 15 kbps which is consistent with measured reported in [19].

A list of equipment and associated cost were also compiled and presented in Table III.

TABLE III
LIST OF EQUIPMENT USED AND COST

Qty	Item	Cost
4	Laptops (Windows XP) - Surplused	Free
1	DeLorme Earthmate GPS LT-20 with Street Atlas	\$99
2	Buffalo WHR 54S Wireless Router/AP	\$80
1	Optical Fiber Training Kit (OFT) – Surplused	Free
1	Linksys WRT 54GS	\$40
1	Asterisk	Free
1	TCP-COM Evaluation Version	Free
2	Cisco IP Phones – Surplused	Free
3	X-Lite	Free
3	Headphones	\$24
1	DD-WRT, OpenWRT	Free
1	ZyXEL (Wi-Fi Wireless Phone)*	Free
1	Linksys VoIP Gateway*	Free
1	Analog Phone Set - Surplused	Free
1	COM Multiplexer / De Multiplexer	Free
1	40 pin FRC to RS-232 Adaptor	\$5
1	NetGear Ethernet Hub – Surplused	Free
1	Temperature Simulator	Free
	Total	\$238

In addition to the demonstration by the integration team, each team delivered a demonstration of their findings and results on their respective network technologies.

CONCLUSION AND RECOMMENDATIONS

This approach in teaching undergraduate data and voice networking has been quite an opportunity for the student to gain a significant appreciation of the challenges related to establishing end-to-end connections particularly for real-time applications. They were confronted with a number of challenges and problems throughout the project lifecycle. These problems were primarily in the protocol conversion, application interfacing and channel performance characterization. Here is a list of what is considered the key learning gains through solving these problems:

- Gaining hands-on experience with end-to-end and system approach for networking and network services;
- Appreciating the critical role of system integration in developing end-to-end communications channels;
- Gaining a strong appreciation of how critical standards are for interoperability between networks and subsystems;
- Understanding that the end-to-end performance of a communication channel is as good as the weakest link (bottleneck);
- Appreciating the small team and inter-teams dynamics;
- Appreciating the capabilities and limitations of network emulation and simulation;

- Acquiring insight into how to evaluate the performance capabilities of different network technologies;
- Gaining insight into different network protocols and models (e.g., RTP, SIP, IP, TCP, UDP, LAN Ethernet 802.3, Wireless 802.11, WAN PPP, NMEA 0183) as well as LAN wireless configurations, such as, AP, Ad Hoc and Bridging/WDS;
- Gaining strong insight into network configuration such as sub-networking and common services (e.g., DHCP); and
- Learning how to select solutions based on criteria such as cost, time to implementation, ease of implementation, value, QoS, etc.

The experiment was a success. The students achieved the project objectives and goals, that is, to deliver a working prototype of a new service using emulated network transport and switching components within the time and budget constraint given by the instructor/coach. Notwithstanding the apparent success we have witnessed, we recognize that there are opportunities for improvement and expansion. The most salient of these are listed for the reader's consideration. Also listed with each opportunity are potential modifications that are being considered to improve the students' experience.

- Adopt more of Problem Based Learning (PBL) concepts, tools and methods.
- Have students self and peer assess their progress on a frequent basis throughout the life-cycle of the project.
- Avoid projects and problems that, while solvable, may require more time to complete than what is available.
- Be more specific in defining milestones and interim written deliverables particularly when it comes to schedule.
- Expand the scope of the services to include video and mobility converged applications.
- Supplement the emulated network technology components to include (1) the Internet (using inexpensive DD-WRT based routers), (2) Public Switched Telephone Network (PSTN), (3) T1 and T3 transport.

ACKNOWLEDGMENT

The author wishes to acknowledge the effort of the following students: Matt Gilkeson, Henry Robertson, Christopher French and Anthony Ward and the contributions of Kenneth Chiang (Com Multiplexer/De-Multiplexer), Joe Rudmin (40 bin OFT to RS-232 adaptor), Jordan Smith (Asterisk on Linksys) and Vernita Fisher for her assistance in the early documentation of parts of this project.

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